DEPSCoR/ONR N000 14-031-0660

Intelligent Agents for Reliable Operation of Electric Warship Power Systems

Distributed Intelligence for Automated Survivability: Program Review and Workshop

August 10-11, 2004

Applied Physics Laboratory, Johns Hopkins University, Laurel MD

Presentation Outline

- **Project management**
  - Individual performers
  - Collaborative efforts
- **Research**
  - Objective
  - Development efforts
  - Product description
  - Technology integration
- **Progress**
  - Results to date
  - Exit criteria
- **Program status**

Project Management

Individual Performers Research Faculty

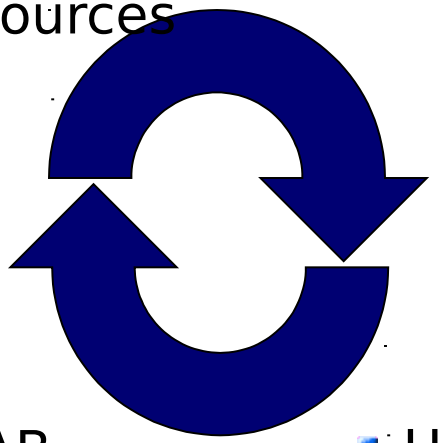
- APERC
  - Distributed resources
  - Power electronics
- LDCSEE
  - APERC's director
  - Principal investigator
  - Power Systems, Control

- NRCCE
  - Energy
- APERC
  - Modeling, simulation
  - Agent technology
  - HIL-simulation and control
- Mathematics
  - Graph algorithms
- LDCSEE, left WVU

Project Management

Individual Performers
Graduate Research Assistants

- Distributed resources
- Control Agents



- DSP, real-time control
- Power electronics

- Agents, MATLAB
- Self-healing aspects

- HIL-Simulation, Real-time control
- Computer Aided Control Design Software

Collaborative Efforts

Current contacts and collaborations

- U. S. Naval Academy, Weapons and Systems Engineering Dept.
  - Electric Shipboard Power System (ESPS) model
- APERC
  - *Electric Power Distribution Systems* Research Group

Potential collaborations

- Center for Advanced Power Systems CAPS, Florida State University
  - HIL-Simulation efforts
  - Real-time and Hardware-in-the-Loop experiments
- TransÉnergy (Hydro-Québec)
  - EMTP software & modeling: Library development
  - EMTP-RV & EMTPWorks

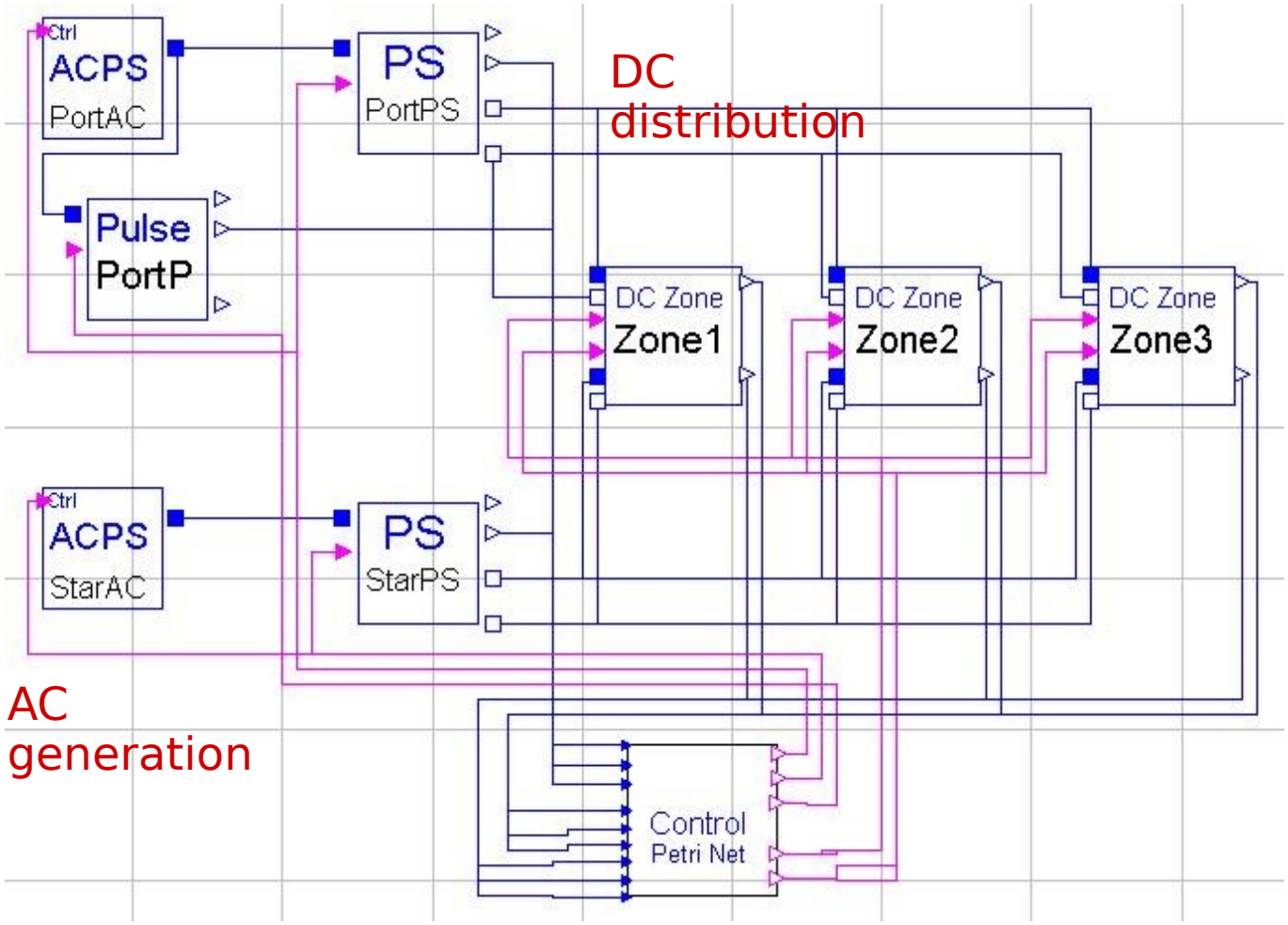
Objective

- Feasible control architecture for ESPS
  - Withstands major disruptions and avoids cascading failures
  - Distributed control algorithms
  - **Fault tolerant system with self-healing mechanism through coordinated distributed agents**
- **Common simulation and analysis tool**
- **Illustration of the proposed techniques** on a realistic test bed
- **Education and training of students**

Object-oriented ESPS Library

- **Multi-domain modeling**
  - Electrical circuits, Mechanics, Logical states, Petri nets
- **Acausal modeling approach - Modelica**
  - Object-oriented modeling language for hybrid systems
  - Input-output interface is not predefined by modeler
  - Use equations only
    ... and automatic translator to find proper input-output assignments
- **Developed Modelica library**
  - Basic components (R, L, C, diodes, ...)
  - Power Electronics (rectifier, ...)
  - Electro-mechanics (induction motor, ...)
  - Petri nets (modified library)
  - Controls (PI, ...)
  - Tested interface to Matlab for networked control

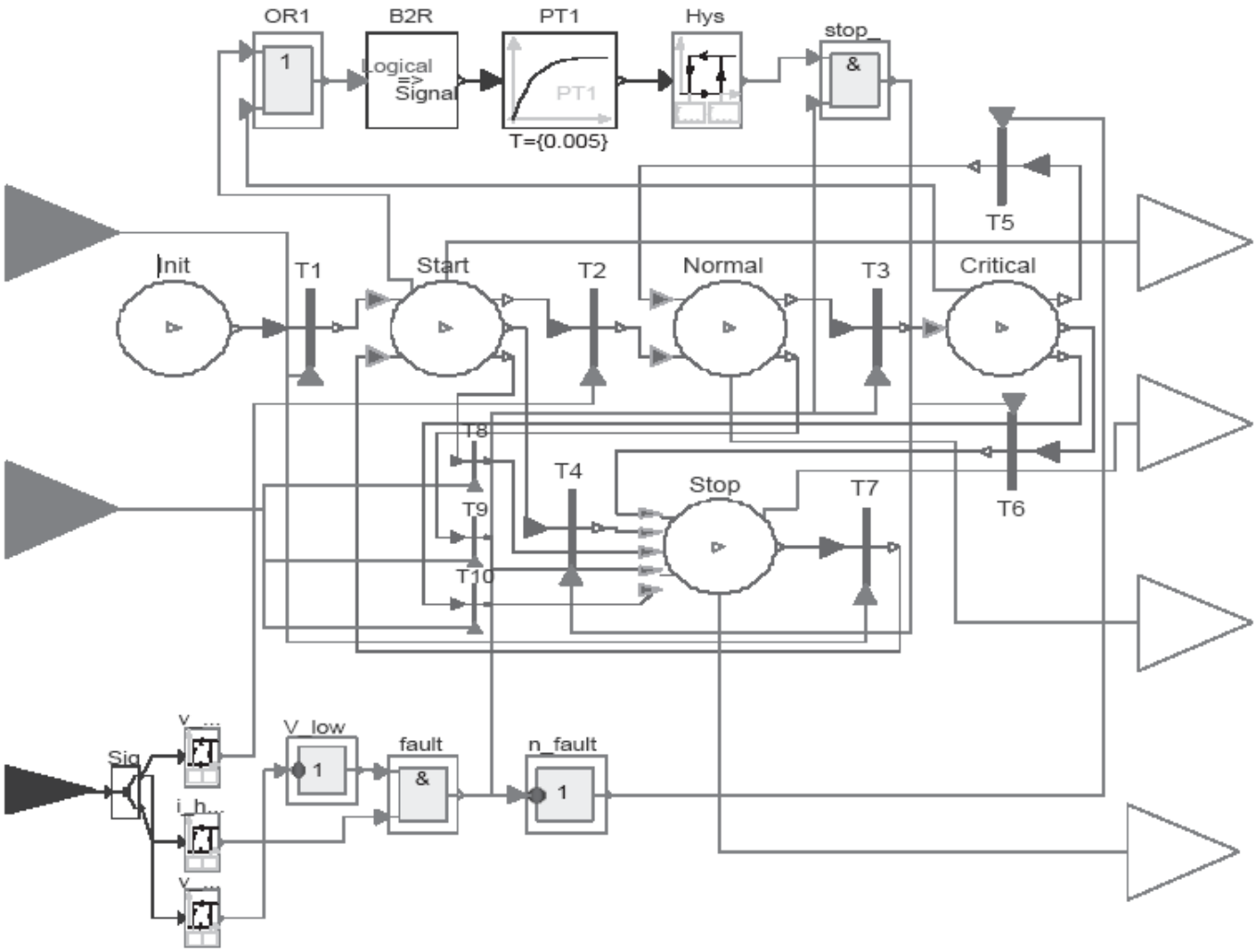
Object-oriented ESPS Library



Modelica

- Multi-domain
- Acausal
- Reusing components
- Hybrid systems
- Developed Power Electronics library

Hybrid System Modeling



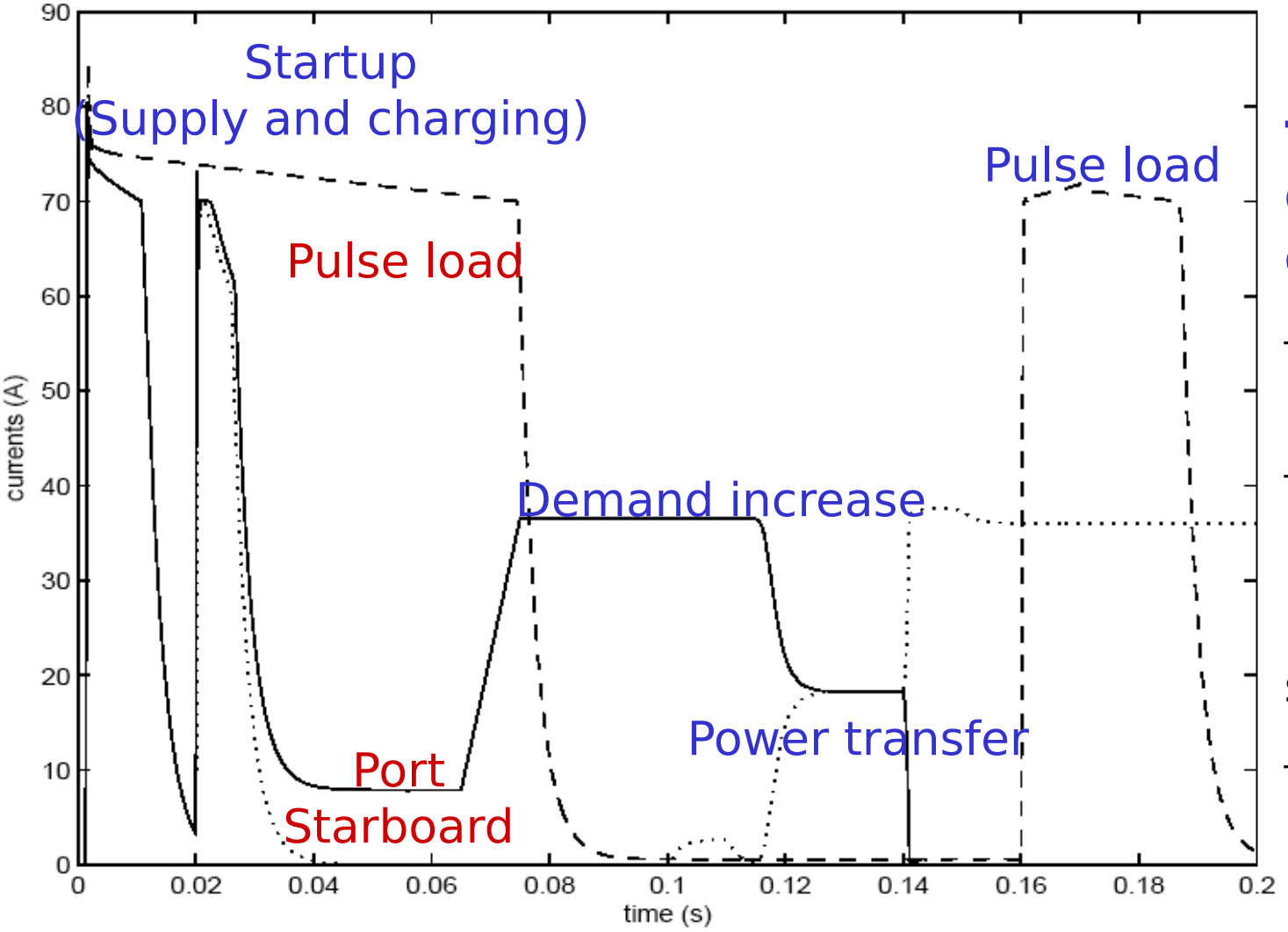
Continuous and logic signals

Petri nets:
Place
Transition
Token

Directed bipartite graph

Local equations integrated with DAE system

Coordination & Reconfiguration



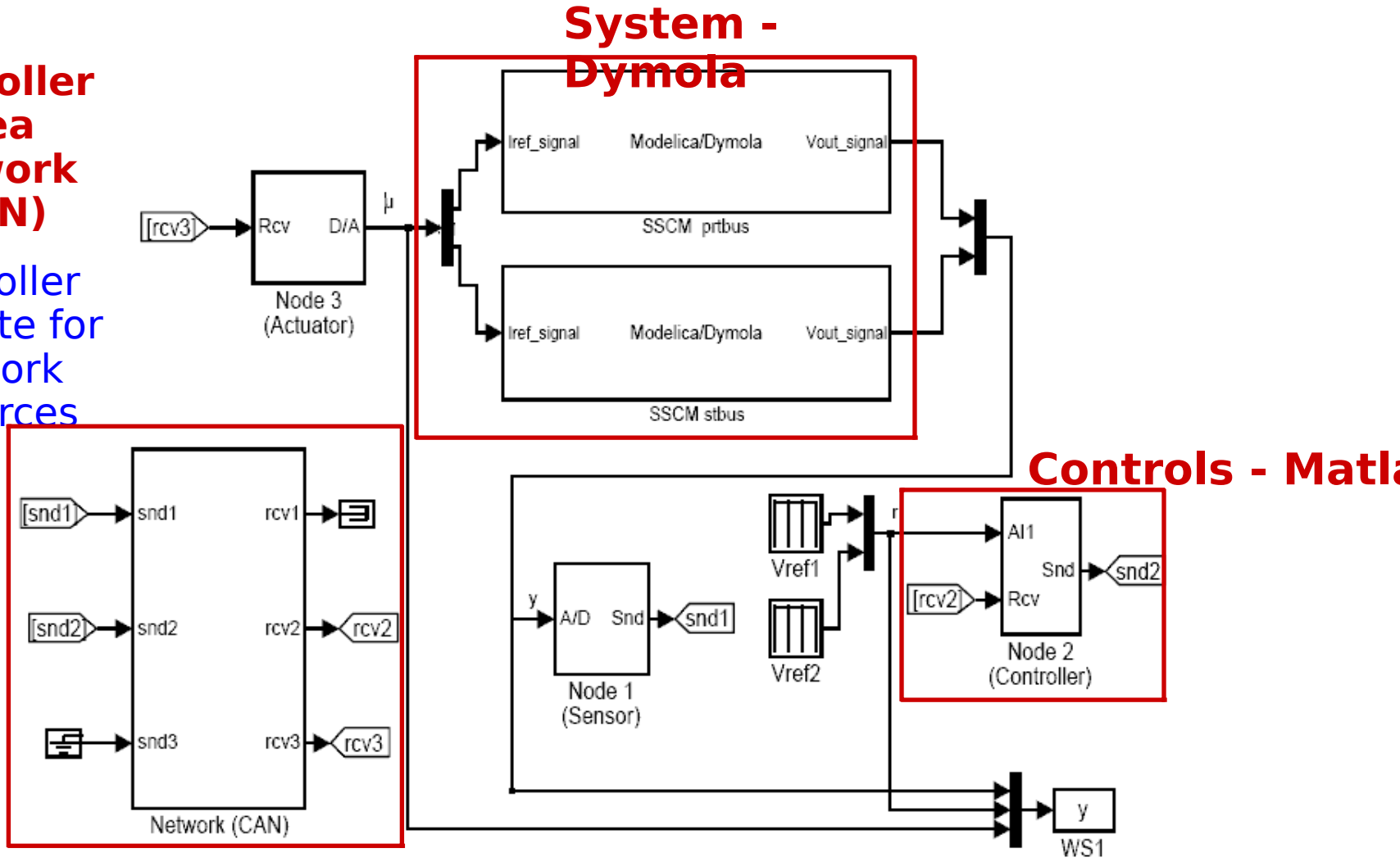
Petri nets for coordination

- Supervisory function
- Automatically switching to backup source
- Reconfigure, e.g., new reference values

Networked Control

Controller Area Network (CAN)

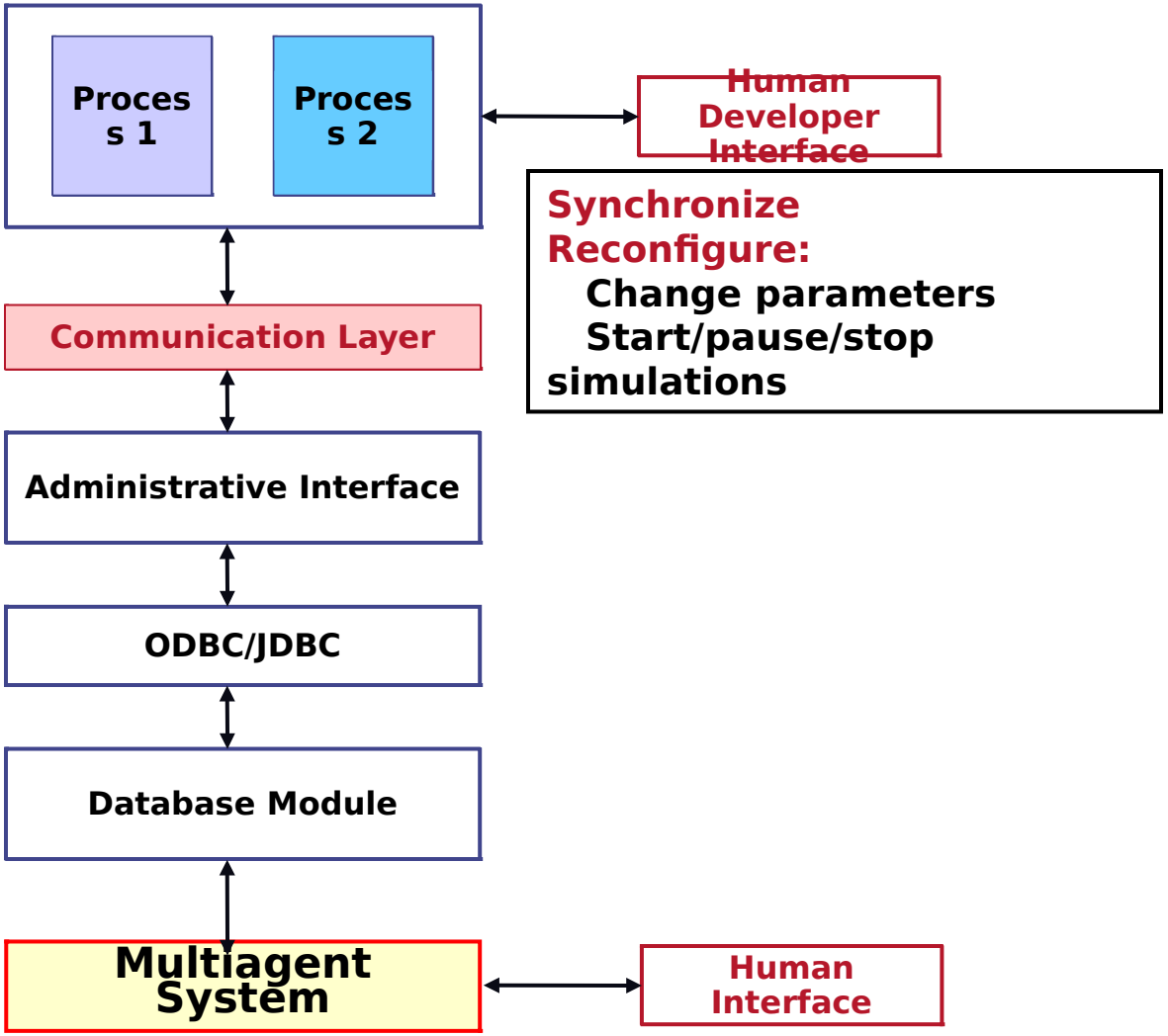
Controller compete for network resources

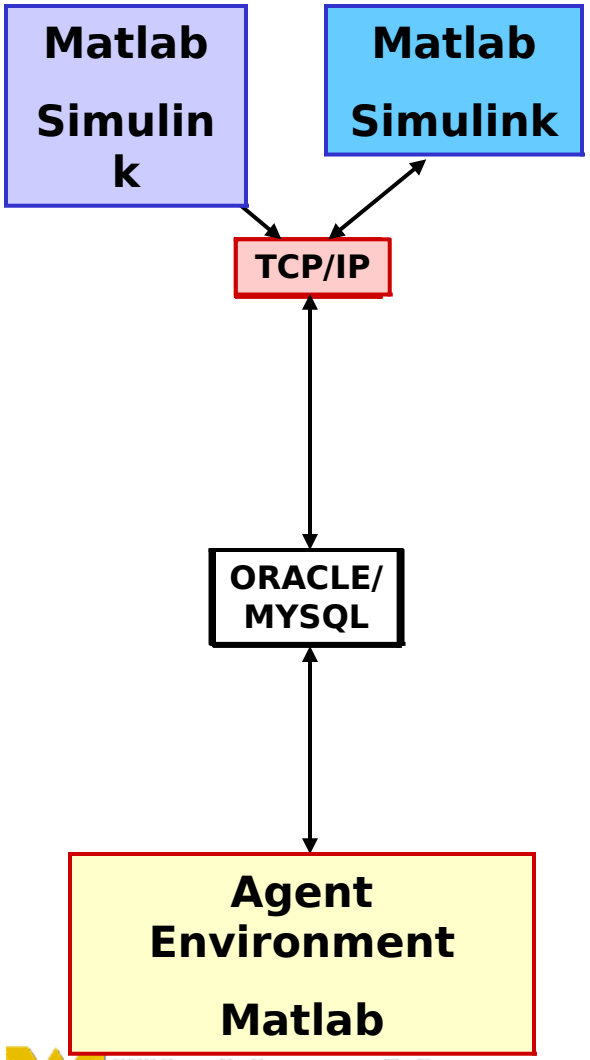


Multi-Agent System

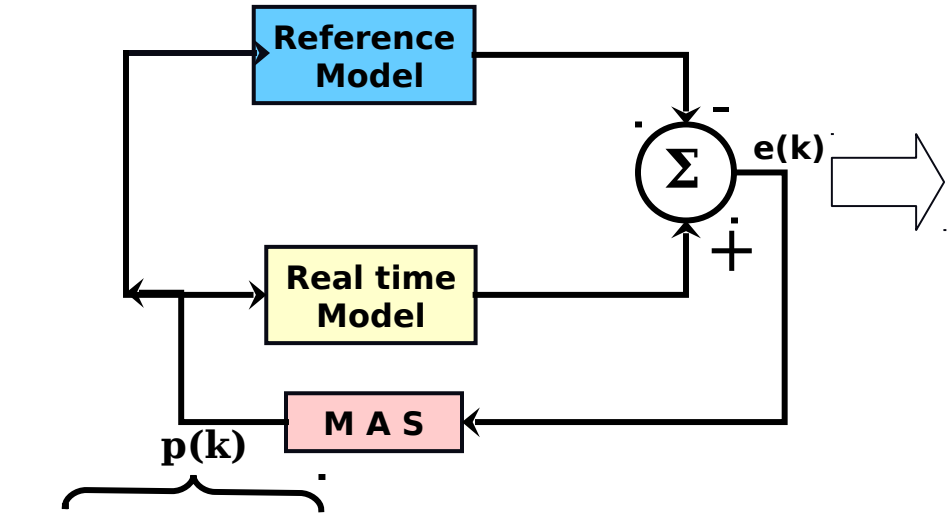
- **Multi-agent system (MAS) prototype**
  - Linking MATLAB/Simulink model with database
    - ESPS testbed with revised controls and additional devices
    - Turbine governor, distributed resources
    - Priorities
  - JAVA-based interface
    - Database connection
    - SQL to query
  - Objective and motivation
    - Energy management integrated with controls
    - Automatic reconfiguration by autonomous MAS

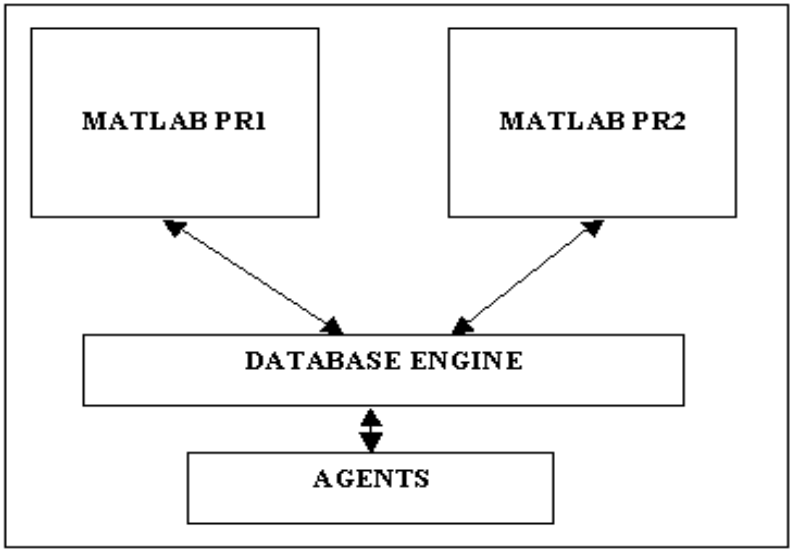
MAS Implementation





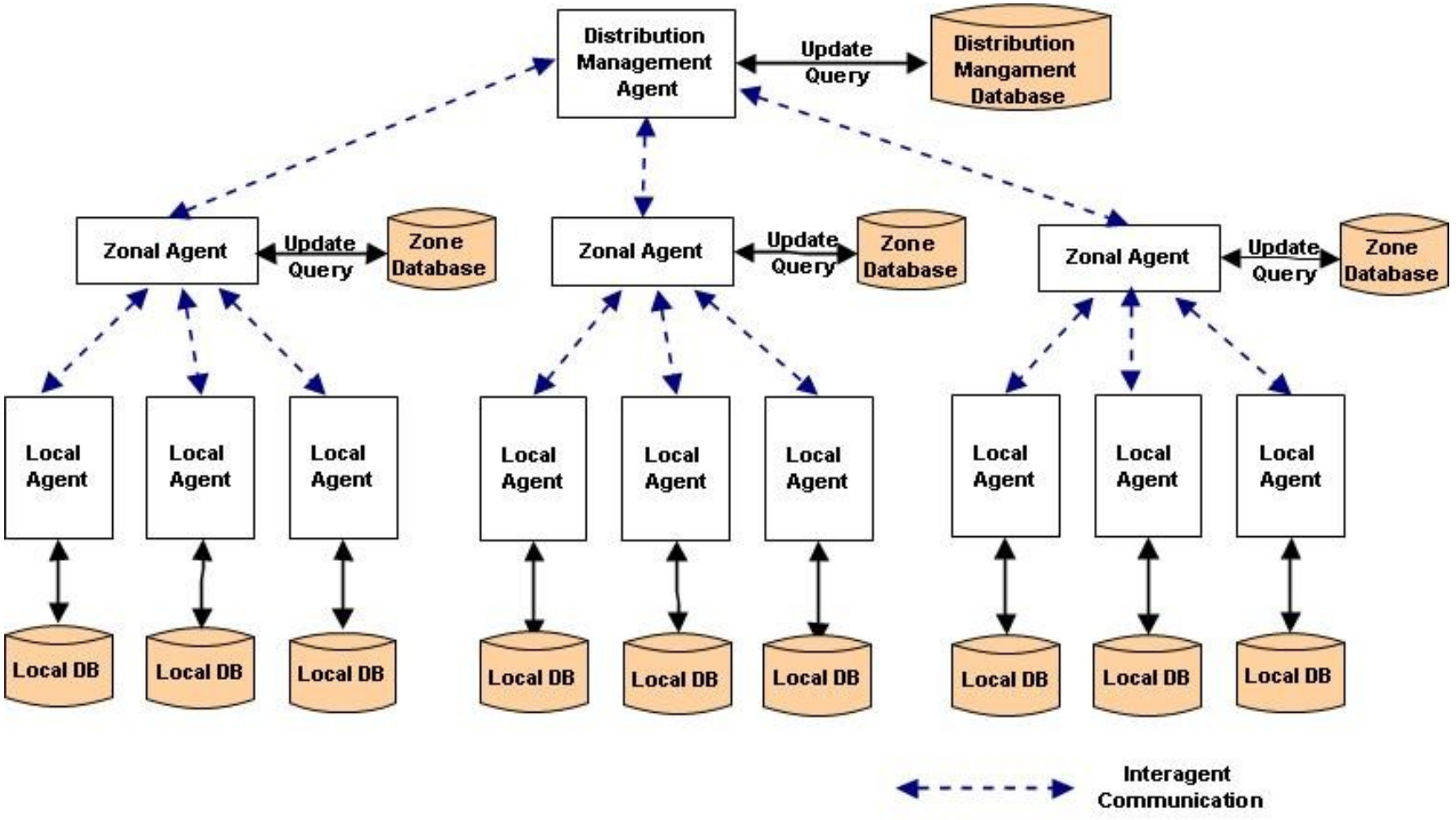
MAS Reference Model



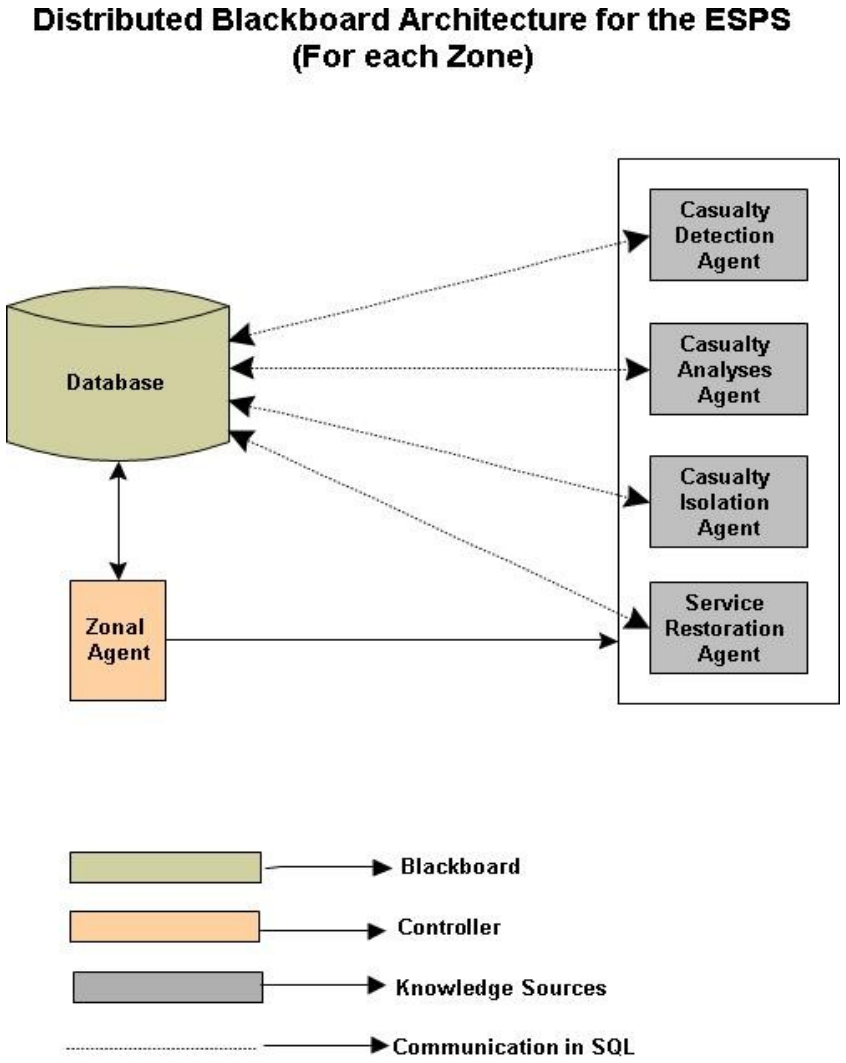


- Two desktop systems, one running the reference model and the other running the “real-time” model
- The reference model machine houses the database
- Simulations are synchronized

MAS Distributed Information Model



MAS Blackboard Architecture



- Structure of zone agent and its communication
- Based on blackboard architecture
- Control component represented by agents
  - Tactical situation (casualty detection)
  - Evaluate threats (casualty analysis)
  - Take appropriate actions (casualty isolation and service restoration)

MAS - Energy Management System

- Maximum flow problem
- ESPS as acyclic directed graph and its residual graph
- Could be solved centrally by linear programming
- Investigating:
  - Simple, distributed self-stabilizing algorithm
  - Local checking and local corrections
  - Asynchronous moves
  - Tolerant to transient faults
  - Adjusts to dynamic changes in network topology and edge capacity
  - Ideas from graph theory and combinatorial optimization

MAS - EMS: Graph Theory

- **Computation model**
  - Each node *i* in graph G corresponds to an agent *i*
  - Node *i* executes its program (algorithm) asynchronously
    - begin
      $G_1 \rightarrow A_1$ (G ... guard, A ... atomic action)
      $G_2 \rightarrow A_2$
      ...
      end
  - Each edge (*i*,*j*) corresponds to a physical directed link
  - Each process *i* contains finite set of local variables
    - Can be read by agent *i* and its neighbours
    - Can be written by agent *i* only
  - Distinguished agents *s* (source) and *t* (target, sink)

Real-time Control and Hardware-in-the-Loop

- **Hardware-in-the-Loop**
  - Provide a small-scale system of the AC-DC shipboard system
  - Link hardware and software
  - Control algorithms
  - Simulation of parts of the system
  - Networked control
- **Motivation**
  - Real-time requirements
  - Education
  - Available in the lab
  - Modern approach to R&D
- **Approach**
  - Real-time operating system: RTAI
  - SCILAB/SCICOS, RTAI-Lab
  - Hardware-testbed

Product Description

- Multi-agent system
  - Software development
  - Control design and algorithms
  - Implementation of a Self-healing system
  - Autonomous energy management system
- Education
  - Real-time control experiments

Technology Integration

- **Human resources**
  - Computer science and software engineering
  - Electrical engineering
  - Control engineering
  - Mathematics
  - Power systems
- **Technology**
  - Software
  - Multi-agent control system
  - Hardware
  - HIL-system

Results to Date

- **Adapted ESPS**
  - Converter controls
  - Multiple loads with priorities
  - Identified models for turbine-governor and distributed resources
- **Modeling and simulation**
  - Modelica library and investigations in EMTP products
  - Small MAS prototype
- **HIL-Experiments**
  - RTOS and interfacing tests

Selected Publications

1. "Simulation and Control of Electric Shipboard Power Systems using Modelica & MATLAB/Simulink," *IEEE PES General Meet.,* Denver, CO, June 2004.
2. "Effects of DGs on Stability," *2004 IEEE PES General Meeting,* Denver, CO, June 2004,
3. "Intelligent Agent Control Concept of Distributed Generators," *Proc. Baha Technical Conference,* May 3-5, 2004.
4. Azra Hasanovic, N.B. Bhatt, A.G. DeGroff, "Robust PSS Control Design or Practical Robust PSS Control Design Through Low Order Transfer Function Identification," *IEEE Transactions on Power Systems*, August 2004.
5. "Robust PSS Design Through Multiobjective Optimization," IEEE PES Power Systems Conference & Exposition, New York, October 2004.
6. "Control Of Microturbines In A Power Distribution System Using Particle Swarm Optimization," *Proc. IEEE PES North American Power Symp.*, Oct. 2003.
7. "Dynamic and Transient Analysis of Power Distribution Systems with Fuel Cells, Part II: Control and Stability Enhancement," *IEEE Trans. on Energy Conversion, June 2004*.
8. "Impact of Fuel Cells on Load-Frequency Control in Power Distribution Systems," *IEEE Transactions on Energy Conversion*, (provisional acceptance).

Exit Criteria

- **Modeling and simulation**
  - Dissemination of results in refereed publications
  - Software and tools
    - Integrated MAS with ESPS
  - HIL: Partly reproduce MAS system controls and performance
- **Education**
  - Student design projects
  - Thesis/Dissertations
    - Self-healing MAS architecture
    - Real-time control

Program Status

- **A three year project**
  - June 1, 2003 – May 31, 2006
- **DEPSCoR/ONR Grant**
  - DEPSCoR
  - ONR
  - Cost-share
    - NRCCE
    - WVURC
    - WVU
    - APERC